

Management of Petroclival Meningiomas: A Review of the Development of Current Therapy

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Abstract

Keywords

- petroclival
- meningioma
- resection
- radiosurgery
- review

The surgical management of petroclival meningioma remains challenging, due to the difficulty of accessing the region and the vital structures adjacent to the origin of these tumors. Petroclival meningiomas were originally considered largely unresectable. Until the 1970s, resection carried a 50% mortality rate, with very high rates of operative morbidity if attempted. However, in the past 40 years, advances in neuroimaging and approaches to the region were refined, and results from resection of petroclival meningiomas have become more acceptable. Today, the developments of a multitude of surgical approaches as well as innovations in neuroimaging and stereotactic radiotherapy have proved powerful options for multimodality management of these challenging tumors.

Introduction

Petroclival meningiomas are lesions arising from the upper two thirds of the clivus with dural attachment centered on the petroclival junction. They are seated medial to the internal auditory meatus and posterior to the gasserian ganglion. This differentiates them from clival meningiomas that arise close to the midline of the clivus.^{1,2} Petroclival lesions displace the brainstem posteriorly and contralaterally, and they may extend into the cavernous and petrosal sinuses, middle cranial fossa, parasellar region, tentorium, foramen magnum, Meckel cave, and/or various other cranial nerve foramina before they become clinically apparent.² In addition, they may also displace or surround cerebrovascular structures of the region and may invade through the dura and/or infiltrate the underlying bone.^{2–4} The natural history of these lesions demonstrates progressive growth and brainstem compression, eventually leading to neurologic decline and inevitable death.^{5–10}

Until the 1970s, these tumors were considered largely unresectable.^{5,11,12} The management of petroclival meningiomas, even with advanced surgical technology and instrumentation, remains a formidable technical challenge to the

skull base surgeon. This article reviews the most important publications from the first description of tumors in this region to the current management strategies for these tumors.

Material and Methods

Queries were performed on Web of Knowledge (Thomson Reuters), using the search terms “petroclival,” “meningioma,” “resection,” “technique,” “radiosurgery,” and “imaging” in varying combination. Articles reviewed here include major series of petroclival meningioma patients and early articles that described tumors of similar anatomical description as later-described explicit petroclival lesions. Data were reviewed and compared for classification of meningiomas in “petroclival” location, preoperative use of various imaging techniques, operative technique, postoperative outcome, and use of adjuvant radiotherapy modalities.

Results

Overall, 88 studies were found on our review of the literature. There were no randomized controlled studies found within our search topics. All publications were retrospective case

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studies, technical reports, or editorials. The publications were organized into their historical relevance, surgical approach, and treatment modality. Studies that did not accurately describe meningiomas of the petroclival region were excluded. Sixty-nine publications were thus selected and are detailed below. Patient demographics and outcome data of major surgical series and radiation therapy series for petroclival meningiomas are summarized in ►Tables 1 and 2, respectively.

Discussion

The 20th Century: From Early Descriptions, Roentgenogram, and Autopsy Studies to the First Surgical Series

Early accounts of lesions in this region of the posterior fossa are clouded by inexact anatomical characterization. Due to limitations of imaging modalities at the time, tumors in the posterior fossa could be only be identified by indirect means. Specifically, skull roentgenograms and angiography revealed displacement of normal anatomical structures, and the location and size of the mass lesion had to be inferred based on these findings. These limitations led to poor outcomes because the relationships of the lesion to critical structures could not be well understood before surgery. Exploratory surgery of the skull base based on the extrapolations of indirect imaging often found no tumor. Additionally, the definition of “petroclival meningioma” was unclear and varied from author to author, at least until Couldwell et al suggested a strict definition in 1996.¹

Cushing and Eisenhardt discussed several cases of tumors in this region in their book *Meningiomas: Their Classification, Regional Behaviour, Life History, and Surgical End Results*.¹¹ They indicated that the first published case of such a tumor was described by Hallopeau,¹³ a 50-year-old female patient with a several-week onset of bilateral upper extremity paresis and painful permanent flexion contractures, followed by similar symptoms in bilateral lower extremities. The patient became dyspneic due to progressive involvement of the diaphragm and accessory respiratory musculature and died of asphyxiation 5 months after presentation. On autopsy a tumor the size of a chestnut was found in the basilar groove involving the occipital foramen and pushing the medulla forward. The tumor was microscopically described as a fibromeningioma. The relevance of this case was later disputed by Cherington and Schneck, who contended that this tumor seemed to actually originate from the foramen magnum.¹⁰ Cushing et al described other selected autopsy cases, originally published by several other author groups, with tumors involving the foramen magnum and the lower third of the clivus. At the time, these tumors were considered inoperable.¹⁴

A few years after the publication of Cushing's *Meningiomas*, Cherington and Schneck published two cases of clivus meningiomas. They discussed the difficulty of decoding the clinical picture and the importance of roentgenograms, particularly vertebral angiography, in the diagnosis of these tumors. Additionally, they noted that the presence of dysphagia, motor tract involvement, and signs of increased intracra-

nial pressure are useful in differentiating symptoms from acoustic neuromas, spheno-occipital chondromas, and brainstem gliomas that can otherwise present with a similar clinical picture. However, their assessment of treatment options also concluded these tumors to be largely inoperable, with a 1-year postoperative survival rate of $\leq 25\%$, even with then-available radiotherapy adjuvant treatments.¹⁰

In 1953, Castellano and Ruggiero classified posterior fossa meningiomas into five categories based on their site of growth and attachment, and they included the posterior surface of the petrous bone as a separate entity.⁵ Olivecrona published his series *Meningiomas of Posterior Surface of the Petrous Bone* in 1967 and similarly declared these lesions to be “inoperable.”¹² Indeed, the operative mortality prior to the 1970s exceeded 50%.^{4,10,14,15} It appears that prior to 1970, only 10 of 26 reported patients in the literature^{5,10–12,14,16,17} survived surgery for a clivus meningioma, and only one¹⁴ had total extirpation of the tumor.

It was not until the implementation of the operative microscope and the advent of microsurgical techniques in the 1970s that a critical advance in the ability to treat lesions in the petroclival region was created. The microscope allowed the neurosurgeon to recognize and dissect along an arachnoidal plane, freeing the tumor from adjacent vital structures. With these new microsurgical techniques, two series (reported by Yaşargil and colleagues and Hakuba et al) demonstrated an operative mortality rate $< 20\%$ (17% and 15%, respectively) for excision of meningiomas of the clivus.^{4,18}

Introduction and Advancement of Imaging Modalities and Development of Microsurgical and Skull Base Strategies

Hakuba et al published the first paper with encouraging results, achieving total resection of six “clival meningiomas.”¹⁸ They (like Cherington and Schneck) also found helpful distinguishing symptoms of these tumors (as compared with acoustic neuromas) to be dysphagia and pyramidal tract involvement, and found that bone erosion on skull roentgenograms and signs of increased intracranial pressure and cerebral angiography helped differentiate clivus meningiomas from intracranial chordomas and brainstem gliomas, respectively. They stressed that the main consideration in deciding the approach to the tumor is the site of dural attachment, so that the feeder vessels can be controlled early in the procedure. They also categorized these tumors based on their site of attachment and advocated a wide approach to avoid brainstem retraction and to help identify critical structures adjacent to or entangled within the tumor. For upper clivus meningiomas extending to the tuberculum sellae, they recommended a combined subfrontal/subtemporal approach; for upper and midclivus lesions, a transpetrosal-transtentorial approach was warranted; and finally, for middle and lower clivus lesions, they advocated a suboccipital approach with craniectomy extension anteroinferiorly to allow for a more lateral exposure than a conventional suboccipital procedure.

Yaşargil et al created the first classification system for basal posterior fossa meningiomas. Utilizing computed

Table 1 Surgical series demographics and outcomes

Study	No. of patients	Mean age, y	Male-to female ratio	Tumor size	GTR (%)	Mean follow-up, mo	Operative mortality (%)	Major morbidity (%)	New CN deficit (%)	Recurrence (%)
Hakuba et al ¹⁸	6	41	1:5		6 (100)	15	1 (17)	3 (50)		
Yaşargil et al ⁴	20				7 (35)		2 (10)	6 (30)	10 (50)	3 (15)
Mayberg and Symon ¹⁹	35	49.5	13:22	2.5–7 cm	9 (26)	34	3 (9)	12 (34)	19 (54)	4 (11)
Al-Mefty et al ²⁹	13	46	2:11	3–7.5 cm	11 (85)	26	0 (0)	1 (8)	4 (31)	1 (8)
Nishimura et al ³⁰	24	47	7:17	3–8 cm	17 (71)	60	2 (8)		20 (83)	5 (21)
Samii et al ¹⁵	24	45	7:17		17 (71)		0 (0)	(17)	11 (46)	
Bricolo et al ³	33	52	12:21		26 (79)	53	3 (9)	6 (18)	25 (76)	3 (9)
Samii and Tatagiba ³¹	36	47	11:25		27		0 (0)	6 (17)	32 (89) ^a	
Couldwell et al ¹	109	51	40:69		75 (69)	72	4 (3.7)	16 (15)	35 (33)	14 (13)
Zentner et al ⁷⁰	19	56	2:17		13	18	1 (5)	2 (11)	10 (53) ^b	0 (0)
Abdel Aziz et al ⁴²	35		6:29		13	50	0 (0)	3 (9)	11 (31)	1 (3)
Little et al ⁷⁴	137	53	38:99		55 (40)	8.3	1 (0.8)	38 (28)	36 (23)	15 (18)
Bambakidis et al ⁷⁷	46	55	6:40	31.5 cm ³ (2–150 cm ³)	9	42	0 (0)	12 (26)	14 (30)	7 (15)
Natarajan et al ⁷⁶	150	51	29:121	3.44 cm (0.79–8.38 cm)	48	101.6	0 (0)	26 (17)	31 (20)	7 (5)

Abbreviations: CN, cranial nerve; GTR, gross total resection.

^a46 total; 14 transient.^bNew CN deficit at any time postoperatively.

Table 2 Radiation series demographics and outcomes

Study	No. of patients	Mean age, y	Male-to-female ratio	Volume treated, mL (mean)	Mean clinical follow-up, mo	Radiographic lesion reduction/stability (%)	Major morbidity (%)	New CN deficit (%)	Tumor enlargement (%)
Subach et al ⁵⁴	23 (primary GKRS) 39 (adjuvant GKRS)	66 50	15:47 (total)	13.3 (14)	38.8 43.5	56 (90.3)	5 (8)	5 (8) ^a	5 (8)
Iwai et al ⁵⁵	24 total 11 (petroclival)	54 (total)		10.9 (7 total)	17.1 (total)	24 (100)	1 (4)	0 (0)	0 (0)
Roche et al ⁵⁶	32	53	5:27	2.2	48	24 (100)	3 (9)	2 (6) transient 0 (0) permanent	0 (0)
Kreil et al ⁷²	200 total 99 (combination) 101 (GKRS)	57	40:160	6.5	95	196 (98)	2 (1)	1 (0.5) transient	4 (2)
Park et al ⁶⁸	75 total 11 (combination) 5 (CRT) 12 (GKRS)	44	15:60 (total)	5.2	52 (GKS)	17 (100)	1 (6)	0 (0)	0 (0)
Flannery et al ⁷³	168 total 97 (primary GKRS) 71 (adjuvant GKRS)	57	44:124	6.1	72	152 (90)	13 (8)	3 (2)	16 (10)
Starke et al ⁶⁹	255 total 28 (petroclival)	55	54:201	5.0	78	220 (86)	6 (2) ^b	22 (8.6) ^c	35 (14)

Abbreviations: CN, cranial nerve; CRT, conventional radiotherapy; GKS, gamma knife surgery.

^aMajor morbidity combined with new or worsening CN deficits.^bNon-CN deficits.^cNew-onset or worsening CN deficit.

tomography (CT) scans and cerebral angiography, these authors created a new classification scheme for tumors arising from the clival region.⁴ Interestingly, they dissented from the opinion that these lesions arise from only a small discrete dural base with underlying bony erosion. In their experience, there were no midline origins, and they concluded that the origins of these tumors were at the any of the lateral sites along the petroclival border, with significant zones of dural adherence overlaying large regions of the sphenopetroclival bony interface. Thus they proposed a new anatomical classification scheme, categorizing tumor origin into clival, petroclival, sphenopetroclival, and sphenoclival meningiomas. The postoperative outcomes were improved from previous series; with five of seven patients who underwent radical resections and six of thirteen who underwent subtotal total resection (STR) classified in "good" condition.

The first article truly focusing on meningiomas of the petroclival region, with relatively good results, was published by Mayberg and Symon.¹⁹ This was the first report of using preoperative CT scans together with cerebral angiography to classify these meningiomas into petrous apex, lateral petrous, petrous tentorium, petrous clivus, clivus only, and clivus sphenoid. Although patients frequently developed new or worsened cranial nerve deficits following resection, their long-term functional status was markedly better overall than previous studies. With this series, the mortality rate was reduced to 9%.

The importance of improved neuroanesthesia and addition of neuromonitoring as an integral part of approaching these skull base lesions was discussed by Sekhar and Schramm in 1987. This was also the first reported use of magnetic resonance imaging (MRI) of the brain for the preoperative evaluation of these lesions.⁶ Additionally, the group discussed the consideration of radiotherapy (RT) for subtotally resected lesions. Although adjuvant RT was not considered standard-of-care at the time, several contemporary authors had recently published studies with promising results.^{20–22} In 1996, Sekhar et al again revisited this topic and again stressed the importance of MRI in the delineation of these lesions, as well as the critical consideration of pial invasion. Specifically, if the pia is invaded, the tumors by definition lose the subarachnoid plane necessary for dissection and also will derive some blood supply from the vertebrobasilar system. Thus there is a much higher risk of major complications if total resection is attempted. Therefore, they stressed that lesions with pial invasion must be subtotally resected with a thin rim of tumor left on the brainstem to avoid permanent neurologic damage. Additionally, they highlighted a point that many other series to date had underemphasized: Early postoperative neurologic symptoms frequently worsened following resection of these tumors (60% of their patients), and this was significantly related to tumor size at the time of surgery. However, the neurologic outcomes of these patients improved with time, with only 16% of patients showing residual neurologic deficits (11% improved from immediate postoperative status and 5% had permanent deficits).²³

As diagnostic imaging modalities improved and were refined, so too were the surgical approaches to the region.

Early on, Decker and Malis suggested a combination of transclival, suboccipital, and subtemporal approaches.²⁴ Derome presented transbasal and trans-bucco-pharyngeal approaches, but he and others found the exposure inadequate.^{4,25–27} As mentioned earlier, Hakuba et al recommended a combined subfrontal/subtemporal approach, transpetrosal-transtentorial approach, or suboccipital approach with anteroinferior extension depending on the attachment site of the meningioma, as did Mayberg et al.^{18,19,28} Both groups found the supra- and infratentorial approach most optimal to resect these lesions. Yaşargil et al touted pterional, subtemporal, or suboccipital approaches, also dependent on the origin of the meningioma.⁴

Al-Mefty, Samii, Nishimura, and Couldwell published detailed analysis of various adaptations of the combined supra- and infratentorial transpetrosal approach that minimizes retraction and eliminates the need to transect the sagittal or superior petrosal sinuses by changing the viewing angle of the operating microscope.^{1,15,29–33} In fact, Erkmén et al have asserted that these tumors "require" a lateral skull base approach with petrous bone resection.³³ Samii and others have discussed their preferred modification of the transpetrosal approach in several publications.^{15,31,34–38} Sekhar et al promoted retromastoid, anterior subtemporal, infratemporal fossa, or a combination of the latter two; they later added a combined posterior subtemporal and presigmoid transpetrosal approach popularized by al-Mefty and Samii, modified with a partial labyrinthectomy to preserve hearing.^{6,21,23,39,40} Cantore et al also recommended several variations of a combined infra- and supratentorial approach, calling it "transmastoid."⁴¹ These refinements in approaches initially saw significant improvements in patient outcomes, although by the mid-2000s most case series had similar (albeit low) rates of postoperative morbidity and mortality.

Several authors have attempted to create a quantified model to predict various factors in the resectability of petroclival meningiomas through cadaveric models.^{42–45} Abdel-Aziz et al developed a novel zoning scheme to evaluate extent of postsurgical brainstem reexpansion after either anterior or posterior petrosal approaches with or without orbitozygomatic osteotomy. They proposed new grading scales based on extent of resection and degree of brainstem decompression. Safavi-Abbasi et al used a balloon catheter to simulate the mass effect of a petroclival meningioma and concluded that a mass lesion in this region created intrinsic retraction and an opening toward the upper clivus that may assist the surgeon in determining the optimal approach to increase working space for these tumors. Siwanuwatn et al found the transcochlear approach provided the widest corridor to the petroclival region, although hearing must be sacrificed by default and the approach places the facial nerve at high risk of injury. Others, however, argue that the transcochlear approach should be reserved for cases necessitating access to the petrous portion of the internal carotid artery, advocating the transcrural and transotic approaches as more versatile exposures with minimized risk to the facial and vestibulocochlear nerves.^{45,46}

Recognition of Adjuvant Radiation Therapy and Introduction of Gamma Knife Surgery

The early experience with irradiation of meningiomas was rather disappointing, and before the 1970s RT was thought to have little value in the management of these tumors.^{47–50} However, in the 1970s and 1980s, several authors began to realize that adjuvant RT could be of benefit in patients with incompletely resected meningiomas.^{20–22,28,51–53} These studies showed that postoperative RT can significantly reduce the rate of local recurrence, implying clinically significant growth arrest or actual elimination of growth potential. The advent of radiosurgical therapy showed further promise for the treatment of petroclival meningiomas, especially after subtotal resection; the tumor remnants could be treated with precisely tailored high-dose radiation, possibly affording long-term control of the disease.

Barbaro et al published an important article in 1987 discussing the role of RT in subtotally resected meningiomas in all locations.²² They considered patients in three groups: gross total resection (GTR) ($n = 51$), STR without adjuvant RT ($n = 30$), and subtotal resection with RT ($n = 54$). Notably, they did not explicitly categorize patients into a “petroclival” group, instead grouping all posterior fossa meningiomas together. The recurrence rate in each group was 4% for the GTR, 60% for STR without RT, and 32% for STR with RT. Additionally, the length of time to recurrence was significantly longer in patients with STR and RT versus STR without RT (125 months versus 66 months, respectively), and there were no complications following radiation therapy. The authors agreed that GTR provides the best opportunity for cure, but they recognized the difficulty in achieving such a result in all patients without significant morbidity and mortality. In subtotally resected tumors, however, their data provided convincing evidence that radiation therapy is critical to prevent or delay recurrence of these lesions.

A large case series (109 patients) was published in 1996.¹ Importantly, they advocated a strict definition for petroclival meningiomas, in light of the varying definitions that preceded in the literature: “Tumors defined as petroclival are those with basal attachments at or medial to the skull base foramina of cranial nerves V through IX, X, and XI.” Although patients in their study did not undergo radiosurgical treatment, the authors discussed the availability of gamma knife surgery (GKS) and RT, and concluded that, specifically for cavernous sinus involvement, radiosurgery may become a “regular adjuvant” to the overall management. Indeed, over the next decades GKS gained significant popularity in the management of these lesions, both as a primary treatment in symptomatic patients with small tumors as well as an adjuvant therapy in STR lesions with sinus invasion or cranial nerve/vascular encasement. Results from these studies demonstrated good tumor control and reduction rates with no mortality and excellent reported morbidity rates.^{54–56}

Following the demonstrated success of GKS for these and other tumors, some questioned the role of microsurgery in the treatment of skull base meningiomas.⁵⁷ The authors argued that treatment goals had shifted from survival to deficit-free survival, and that the rates of morbidity from

attempted complete resection were unacceptable. Additionally, the literature showed a much lower risk of cranial nerve deficits (along with no risk of wound infection or cerebrospinal fluid leak), and 15-year progression rates were equal, or slightly better, for GKS compared with Simpson grade I resection. They did concede that some skull base tumors are poorly suited for primary radiosurgery, such as those in intimate proximity to the optic nerve; however, most skull base tumors causing significant symptoms secondary to mass effect may be treated effectively with surgical debulking, followed by radiosurgery for functional preservation and tumor inactivation.

Clearly, the role of radiosurgery in the treatment of these lesions is up for debate. Most authors have concluded that the best chance of cure lies with GTR of the tumor. However, most series do not show a greater risk of recurrence when comparing near-total or subtotal resection with GTR (although the explanation of these data is presently unclear). Most also recognize the unlikelihood of achieving a GTR in every case with optimal functional outcomes. Indeed, the philosophy of neurosurgical treatment in general has shifted from ideal operative results to optimal patient function after treatment.⁴² The vast majority of data also shows that radiosurgery is extremely effective in controlling tumor growth in the short term, and it carries the added benefits of avoiding an intracranial operation. However, radiosurgery is not without its own inherent risks and side effects. Benign skull base meningiomas have been shown to exhibit aggressive behavior following the failure of radiosurgical control, with unpredictable time frames to progression.⁵⁸ Attempting surgical resection after a patient has undergone radiosurgery is a difficult undertaking, with decreased chance of achieving GTR and increased risk of complications. Radiosurgery may not be feasible for large tumors or tumors in close vicinity to radiosensitive structures, although fractionated RT may be used in these cases.^{59,60} The risk of radiation-induced malignancy following treatment of meningiomas and other tumors is also debated.^{61–67} Finally, recent epidemiological results have shown less optimistic long-term survival than the short-term control rates have suggested (53% 15-year survival with 67% of patient mortality caused by meningioma).⁶¹

We agree with others that the best treatment of these formidable lesions is to resect as much of the tumor as is safely possible, with the additional objective of shaping the residual tumor to an ideal radiosurgical target for adjuvant treatment.⁴² Multiple surgical approaches may be warranted (and in fact are utilized regularly at our institution) to accomplish these goals. For smaller lesions, GKS remains a viable primary treatment option.⁶⁸

Development of Modern Multimodality Treatment Strategies

As stated recently, “Neurosurgeons must be careful not to turn the cure into something worse than the disease. In particular, the benefits of complete resection must be weighed against the possibility of associated morbidity and even mortality . . . the serious complications of resection, while less frequent today are no less devastating for patients

who suffer them.”⁶⁹ In light of the published data showing reduced yet still significant rates of morbidity and mortality following GTR of petroclival meningiomas, several authors began to shift their philosophy away from aggressive resection strategies to consideration of STR as a viable alternative. Some authors consider STR a viable primary treatment goal in patients with brainstem and/or cavernous sinus invasion to avoid permanent neurologic deficits, or in the elderly if the growth rate of the patient’s tumor is very slow.^{70,71}

The natural history of petroclival meningiomas in patients managed conservatively (i.e., no neurosurgical or radiosurgical treatment) over a minimum of 4 years has also been studied.⁹ Up to 50% of asymptomatic patients developed cranial nerve palsy and 20% of patients with preexisting palsies developed new cranial nerve deficits. A wide variety of growth rates, even within the same histologic grade, were observed; overall growth rates were 0.81 mm/year in diameter or 0.81 cm³/year in volume. Statistically significant correlations were found between infratentorial growth and moderate/severe functional deterioration (defined as a drop of 20 or 30 points from baseline on the Karnofsky performance score, respectively) and between tumor growth index and the severity of functional deterioration. Additionally, brainstem compression/displacement influenced functional scores, and an increase in the tumor growth index correlates with functional or clinical deterioration. This last relationship is particularly intriguing because the growth index invariably increases prior to deterioration of the patient and trends of increased tumor growth rates in small and medium size tumors has been found. Based on this data, the authors advocated surgical extirpation for small and medium size tumors in young symptomatic patients who are otherwise healthy; older patients or poor surgical candidates should be offered stereotactic radiosurgery. Asymptomatic patients could conceivably be monitored with meticulous radiologic follow-up; once an increase in growth rate is observed, treatment should be offered urgently.

Progression-free survival for patients undergoing GKS at 5 and 10 years (98.5% and 97.2%, respectively) has been compared favorably with microsurgical conventional RT, or LIN-AC-based radiosurgical results.⁷² Others have shown 10-year control rates similar to that of Simpson grade I resection of benign meningiomas, providing further evidence of the safety and efficacy of stereotactic radiosurgery for newly found small symptomatic tumors.⁷³ These studies have also advocated a change in surgical objective from radical resection to preservation of function and preservation of as much normal tissue as possible, with adjuvant GKS to treat the remaining tumor burden.

An analysis of risk factors for postoperative neurologic morbidity and recurrence rates found that recurrence rates after GTR and near total resection (NTR) did not significantly differ, although STR and residual tumor in the cavernous sinus did increase the risk of recurrence.⁷⁴ Intraoperatively defined tumor characteristics were critical in the identification of patients with increased risk of postoperative deficits; in the high-risk subset of patients, pursuing NTR instead of GTR led to reduced postoperative morbidity without an

increase in tumor recurrence rates. Others have discussed experience with multimodality treatment, with more favorable outcomes in patients with incomplete resection with or without adjuvant radiation over GTR.⁶⁸ Minimally invasive approaches as a treatment option for these lesions has also been suggested.⁷⁵

The largest multimodality (albeit primarily surgically managed) petroclival meningioma study to date revealed significant long-term disability in patients undergoing resection; however, the authors concluded that the “excellent quality of life at the time of the long-term follow-up” warranted aggressive but judicious resection, with or without adjuvant radiosurgery for residual tumor.⁷⁶ Others have analyzed outcomes based on choice of approach; interestingly, these authors advocated watchful waiting after STR when the remaining tumor burden is low, as opposed to a protocol of radiosurgery for tumor remnants.⁷⁷ However, several commentaries (by Kawase, Nanda, Sekhar, Ware, and al-Mefty) criticized the article for incomparable groupings, as well as the decision by the authors to approach these tumors by two exposures and without the preoperative goal of GTR. This correspondence further illustrates the differing philosophies in treating this disease.

A retrospective review of several surgical series found difficulty in comparing patients between studies due to the heterogeneity of data points reported, variances in preoperative radiographic evaluation, discrepancies in the categorization of petroclival meningiomas, differences in operative approaches and treatment algorithms, and so on.⁷⁸ However, the GTR rate of these tumors was found to be 49% of all patients, with a 34% rate of neurologic deficit within 3 months posttreatment and a 1-year mortality rate of 1.4%. Analysis of functional outcomes for survivors at 1 year was promising, with > 75% of patients returning to work or able to perform activities of daily living independently.

This review has multiple limitations. The publications analyzed are universally retrospective, uncontrolled, and nonrandomized studies at single or a few institutions. Although many of the authors are highly regarded in their operative ability, this review cannot control for surgeon preference or experience with specific approaches among all authors. Additionally, the rarity of petroclival meningiomas, variations in treatment philosophies, and heterogeneity in the types of data reported add to the convoluted picture. However, it is clear that the development of microsurgical techniques and skull base approaches, a better understanding of the pathology and anatomy of these lesions, development of improved imaging, neuromonitoring and neuroanesthesia, and the introduction of radiosurgery have led to the current multimodality treatment. Several authors have published series analyzing long-term functional outcomes following various treatment modalities for these lesions.^{79–82} It appears that the current consensus is to attempt radical resection for growing, symptomatic, and/or larger size tumors, with careful intraoperative monitoring and judgment. Residual growing tumor or smaller tumors may be treated with GKS. With this strategy, tumor control as well as preservation of quality of life can be optimally achieved.

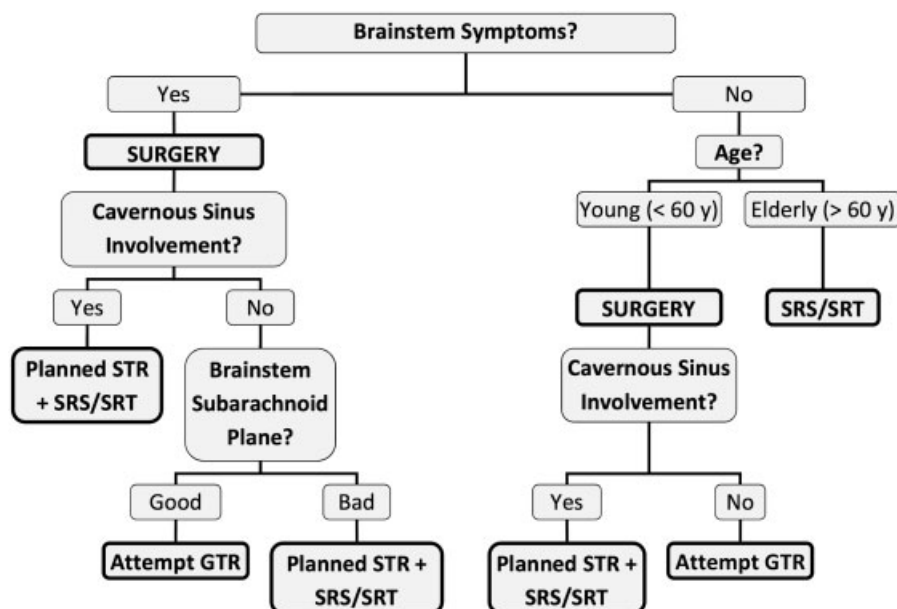


Fig. 1 Management algorithm for petroclival meningiomas. GTR, gross total resection; SRS, stereotactic radiosurgery; SRT, stereotactic radiotherapy; STR, subtotal resection.

Conclusion

Despite development of modern surgical technology and multimodality therapy, petroclival meningiomas continue to present a treatment challenge. In our own management of these tumors, four major variables exist that influence treatment options in these patients: (1) the presence or absence of brainstem symptoms, (2) involvement of the cavernous sinus, (3) patient age, and (4) the presence or absence of a subarachnoid plane between the tumor and brainstem. We summarize treatment recommendations based on these variables in ► **Fig. 1**. The optimal treatment in symptomatic patients regardless of size remains GTR, if feasible. However, functional outcome and quality of life have to be considered as well, and radiosurgery has been shown to be a very effective option for tumor in the cavernous sinus as well as for residual disease. Therefore, for patients with radiographic evidence of cavernous sinus involvement, planned STR with decompression of cranial nerves and removal of tumor from radiosensitive structures in combination with adjuvant radiosurgery has led to good functional outcomes. We also use this strategy when the tumor has obliterated the subarachnoid plane and is adherent to the brainstem. Asymptomatic tumors are controversial because growth rates are variable and difficult to predict. If the patient is likely to live long enough for the tumor to grow and cause symptoms, we recommend surgery, with cavernous sinus involvement dictating our surgical goal. Elderly patients with asymptomatic lesions who desire treatment are offered radiosurgery or RT for tumor control; close radiologic follow-up may also be used, and radiosurgery/RT used if there is evidence of tumor progression.

Conflicts of Interest

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this article.

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